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**TASK ORDER NUMBER 5TS5703D035W:
DEMONSTRATE ALTERNATIVE AIRCRAFT
DEICERS – PHASE III**



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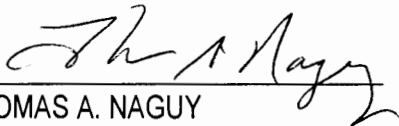
**MATERIALS AND MANUFACTURING DIRECTORATE
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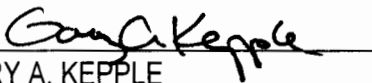
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14. ABSTRACT United States Air Force installations are seeking alternatives to deicing fluids used on aircraft. The current propylene glycol-based fluids used create a significant environmental compliance and pollution prevention issue for the Air Force installations. The Air Force Research Laboratory (AFRL) has identified METSS ADF-2 as a potential aircraft deicing fluid to replace propylene glycol (PG) based fluids. This fluid has been tested and certified in accordance with aerospace material specification (AMS) 1424D, <i>Deicing/Anti-icing Fluid, Aircraft SAE Type I</i> . The objective of this demonstration is to test the performance of METSS ADF-2 in the field on Air Force aircraft, specifically a KC-135R at the Niagara Falls Air Reserve Station (NFARS). Concurrent Technologies Corporation (CTC) was tasked, as an independent evaluator, to demonstrate METSS ADF-2. The specific objectives of this demonstration were to: 1) illustrate the effectiveness of METSS ADF-2 as an operationally suitable deicing fluid; 2) compare the deicing properties of METSS ADF-2 directly against the currently used PG-based deicing fluids in an operational environment; and 3) determine the post-flight migration characteristics of METSS ADF-2 following successful operational use of the fluid.					
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TABLE OF CONTENTS

	Page
LIST OF ACRONYMS	ii
EXECUTIVE SUMMARY	iii
1.0 INTRODUCTION	1
2.0 DEMONSTRATION OBJECTIVES.....	2
3.0 DEMONSTRATION PREPARATION.....	2
3.1 METSS ADF-2 Preparation.....	3
4.0 DEMONSTRATION	3
4.1 Planned Demonstration Schedule	3
4.2 Activities Prior to Demonstration	4
4.3 Demonstration Activities/Observations for Day 1	4
4.4 Demonstration Activities/Observations for Day 2.....	5
4.5 Demonstration Activities/Observations for Day 3.....	5
4.5.1 Deicing Fluid Application / Surface Conditions.....	6
4.5.2 METSS ADF-2 Application Observations	8
4.5.3 Flight Information.....	10
4.5.4 Post Flight Observations	10
5.0 CONCLUSIONS.....	13
6.0 RECOMMENDATIONS.....	13

LIST OF TABLES

Table 1. Planned Demonstration Schedule Summary.....	4
Table 2. Flight Details.....	10

LIST OF FIGURES

Figure 1. METSS ADF-2 Totes and Secondary Containment.....	3
Figure 2. Deicing truck being filled with METSS ADF-2.....	5
Figure 3. Snow on Aircraft Prior to Deicing with METSS ADF-2	7
Figure 4. MD Robotics Ice Detection Equipment	7
Figure 5. Application of METSS ADF-2.....	8
Figure 6. METSS ADF-2 Applied to Aircraft	9
Figure 7. Deicing Truck Residue.....	9
Figure 8. METSS ADF-2 Residual Film on Windshield and Aft Windows	10
Figure 9. METSS Residual Film on Engine Cowling.....	11
Figure 10. Heat Effect on METSS ADF-2 Residue.....	11
Figure 11. Engine Cowling and Trailing Edge of the Engine Nacelle after Washing.....	12
Figure 12. Engine Cowling and Trailing Edge of the Engine Nacelle after Flight of the Aircraft Deiced with PG-based Deicer	12

LIST OF APPENDICES

Appendix A: METSS ADF-2 Certificate of Analysis (COA)
Appendix B: Weather Condition Tables for Demonstration Dates
Appendix C: MD Robotics Summary

LIST OF ACRONYMS

AFRL	Air Force Research Laboratory
AMS	Aerospace Material Specification
ANG	Air National Guard
ARW	Air Force Refueling Wing
BOD	biochemical oxygen demand
COA	Certificate of Analysis
CTC	Concurrent Technologies Corporation
DoD	Department of Defense
GSA	General Services Administration
NFARS	Niagara Falls Air Reserve Station
PG	Propylene glycol
POC	Point of Contact
PAR	Potential Alternatives Report
MTMS	Military Test Method Standard
RTU	Ready to Use
SAE	The Engineering Society for Advanced Mobility (Land, Sea, Air and Space)
SPO	System Program Office
USAF	United States Air Force

Task Order ID: 5TS5702D035W

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SAE-AMS 1424D (Type I aircraft fluids)

SAE-AMS 1428C (Types II, III, and IV aircraft fluids)

SAE-AMS 1435 (liquid runway)

SAE-AMS 1431 (solid runway)

AFI 32-1002 *Snow & Ice Control* (airfield deicing and anti-icing)

TO 42C-1-2, Change 3, 1 May 2000

Aircraft specific TO's not listed.

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EXECUTIVE SUMMARY

United States Air Force installations are seeking alternatives to deicing fluids used on aircraft. The current propylene glycol-based fluids used create a significant environmental compliance and pollution prevention issue for the Air Force installations. The Air Force Research Laboratory (AFRL) has identified METSS ADF-2 as a potential aircraft deicing fluid to replace propylene glycol (PG) based fluids. This fluid has been tested and certified in accordance with aerospace material specification (AMS) 1424D, *Deicing/Anti-icing, Fluid, Aircraft SAE Type I*. The objective of this demonstration is to test the performance of METSS ADF-2 in the field on Air Force aircraft, specifically a KC-135R at the Niagara Falls Air Reserve Station (NFARS). Concurrent Technologies Corporation (CTC) was tasked, as an independent evaluator, to demonstrate METSS ADF-2.

The specific objectives of this demonstration were to: 1) illustrate the effectiveness of METSS ADF-2 as an operationally suitable deicing fluid; 2) compare the deicing properties of METSS ADF-2 directly against the currently used PG-based deicing fluids in an operational environment; and 3) determine the post-flight migration characteristics of METSS ADF-2 following successful operational use of the fluid.

Demonstration activities were limited to applying METSS ADF-2 to one aircraft with very little snow/frost on the surface. Therefore, CTC was unable to determine the actual deicing effectiveness of METSS ADF-2. However, the heated METSS ADF-2 was able to effectively remove the small amount of snow and frost on the demonstration aircraft and it was deemed to be compatible with all deicing equipment utilized in this demonstration. The fluid wetted the surface very well, streaking and/or fish eyes were not observed, and no significant foaming was present upon application. In general, the application properties of METSS ADF-2 however, were similar to that of the current PG-based deicer.

Shortly after the application (within approximately five minutes) of METSS ADF-2, the fluid thickened. Post-flight inspection of the aircraft showed that the METSS ADF-2 did not migrate like the typical PG-based fluids. Rather, it remained as a thick fluid on the surface. This thickening creates at least two major concerns: 1) visibility could be seriously impaired on any window surface and 2) additional thrust may be required to maintain speed due to added drag of the fluid that remains on the aircraft during flight. The West Virginia and Iowa National Guards were contacted by AFRL after the demonstration, and both deicing crews confirmed that similar observations were made in the field when using the METSS ADF-2 for deicing in the '03-'04 winter season.

Because the fluid thickened after application on the aircraft surface, the team does not recommend that the current formulation of METSS ADF-2 be used for deicing on any aircraft in the United States Air Force. The CTC team also believes that the Air Force should consider adding some performance testing for deicing fluids, in addition to those in The Engineering Society for Advanced Mobility (Land, Sea, Air, and Space) (SAE) certification. This recommended performance testing would include subjecting the candidate deicing fluids to studies, at the bench level, involving ice removal capability at various ice thickness levels and types of artificial precipitation, sheering ability, and surface wetting ability, as a few examples. To date, the Air Force has ceased further procurement of the fluid and has issued a maintenance advisory to inform all bases of the problems associated with the use of METSS ADF-2. In addition, a "tiger team", consisting of representatives from the Air Force and METSS, as well other DoD participants, has been formed to determine the cause of the thickening fluid and develop alternative formulations to rectify the issue.

1.0 INTRODUCTION

A high-priority need for the Air Force and Department of Defense (DoD) continues to be alternative deicing solutions for aircraft. Propylene glycol (PG), the current deicing fluid of choice, represents a significant potential environmental liability because glycol-based deicing formulations exert a high biochemical oxygen demand (BOD) on receiving waters. The Air Force Environmental Development Planning (EDP) database has two high priority needs that are associated with capture and recycle, minimization of use, and environmentally-friendly alternatives to PG. They are 1) Need Assessment Summary # 914 - Environmental Improvements to Aircraft Deicing Operations - Provide a more environmentally benign chemical than propylene glycol and 2) Need Assessment Summary # 1443 - Provide an alternative means of removing and preventing aircraft icing other than using Ethylene/Propylene Glycol. A full description of each of these needs is available at the EDP website: <http://xre22.brooks.af.mil>.

To meet the above needs, Air Force Research Laboratory (AFRL) has undertaken a three-phased project to identify potential replacements for PG-based aircraft deicing fluids. In July 2002, Concurrent Technologies Corporation (CTC) completed an effort identifying alternatives to PG-based deicing fluids for the United States Air Force (USAF) under phase one. At the conclusion of that effort, a Potential Alternatives Report (PAR), dated July 12, 2002, was submitted which, identified the current requirements and any alternatives to the current deicing fluids. As a result of the phase one effort, a few non-glycol aircraft deicing fluids were identified as meeting the applicable aerospace material specification (AMS), and CTC recommended that these products be considered for further evaluation to determine their compatibility with USAF-specific substrates.

Under the second phase, CTC coordinated with AFRL to finalize a material compatibility test plan for two potential aircraft deicing alternatives. The material compatibility testing focused on USAF aircraft and airfield substrates with the technical approach patterned after *The Qualification of Ice Control Materials for Air Force Applications*, AFRL-ML-WP-TR-2000-4149, specifically Appendix B "The Draft Military Test Method Standard" (MTMS), along with the *Testing of Aircraft Runway Ice Control Products*, AFRL-ML-WP-TR-1999-4040 (Materials Compatibility Report), for further clarification of testing procedures/parameters. The results of these testing efforts showed that METSS ADF-2 was a candidate aircraft deicing fluid to replace PG-based fluids.

The Air Force has adopted commercial acceptance criteria for the qualification of deicing fluids, which is AMS 1424D for Type I aircraft deicing fluids. To be used on Air Force aircraft, a fluid first must pass the AMS 1424D requirements and, then, be accepted by the appropriate System Program Office (SPO) for the weapon system. Ideally, a full-scale demonstration should be completed prior to accepting the fluid for use in order to verify application properties, compatibility to existing equipment, as well as its overall effectiveness compared to the currently used deicing fluid. This demonstration effort is AFRL's third phase for identifying an alternative aircraft deicer.

METSS ADF-2 had passed performance testing in accordance with AMS 1424D, *Deicing/Anti-icing, Fluid, Aircraft SAE Type I* and, prior to the demonstration

(documented in this report), was granted blanket approval for all applications of Type I aircraft deicing fluids on the KC-135 (covered under TO 1C-135-2-2) and the C-130. However, due the demonstration results of ADF-2, it was deemed necessary by the Air Force to revoke this approval.

2.0 DEMONSTRATION OBJECTIVES

CTC acted as an independent evaluator and was tasked with the third phase of this effort to test the performance of METSS ADF-2 in the field on Air Force aircraft, specifically a KC-135 at the Niagara Falls Air Reserve Station (NFARS). The objective of this demonstration was to compare METSS ADF-2 with a conventional PG-based deicer by gathering objective and subjective data. This comparison data is to provide the Air Force with valuable information to aid in the determination of whether to support the implementation of METSS ADF-2 Air Force-wide. The specific objectives of this demonstration were as follows:

- Demonstrate the effectiveness of METSS ADF-2 as an operationally suitable deicing fluid.
- Compare the deicing properties of METSS ADF-2 against the currently used PG-based deicing fluid in an operational environment.
- Determine the post-flight migration characteristics of METSS ADF-2 following successful operational use of the fluid.

3.0 DEMONSTRATION PREPARATION

The alternative aircraft deicer demonstration was hosted by the 107th Air Refueling Wing (ARW) of the Air National Guard (ANG) at NFARS in Niagara Falls, New York. AFRL and *CTC* representatives traveled to NFARS on 4 December 2003 to conduct a planning meeting and a site visit. During this visit, the demonstration team representatives were introduced to personnel that would assist with the demonstration. The METSS ADF-2 product was introduced to site personnel, and the planned schedule of activities was discussed. A facility tour also was conducted to survey the demonstration and storage areas and inspect the equipment that would be used for the demonstration.

After the site visit, weekly planning meetings were held via teleconference to finalize the demonstration details. *CTC* personnel coordinated the teleconferences for the demonstration team, which included AFRL and NFARS, other DoD personnel, and representatives from *CTC* and METSS. As a result of the planning meetings, the demonstration team was able to finalize the following:

- The schedule and specific demonstration activities,
- The pertinent information needed to acquire the proper approvals prior to conducting the demonstration,
- The necessary equipment needed to conduct the demonstration (including the use of the infrared ice detection equipment to be provided and operated by MD Robotics), and
- The roles and responsibilities of each demonstration participant.

3.1 METSS ADF-2 Preparation

For the demonstration, CTC purchased 2,200 gallons of the METSS ADF-2 deicer in a Ready-To-Use (RTU) formulation from Orison Corporation. Eight 275-gallon totes were shipped to NFARS and delivered on 29 January 2004. The secondary containment unit required for storage at NFARS was purchased from ChemTech International and also delivered on 29 January 2004. Figure 1 illustrates the eight totes, as they were stored in the secondary containment prior to use.

METSS provided a Certificate of Analysis (COA) for the batch of material that was provided for this demonstration. The COA (See Appendix A) verified that the material was within specification tolerances.

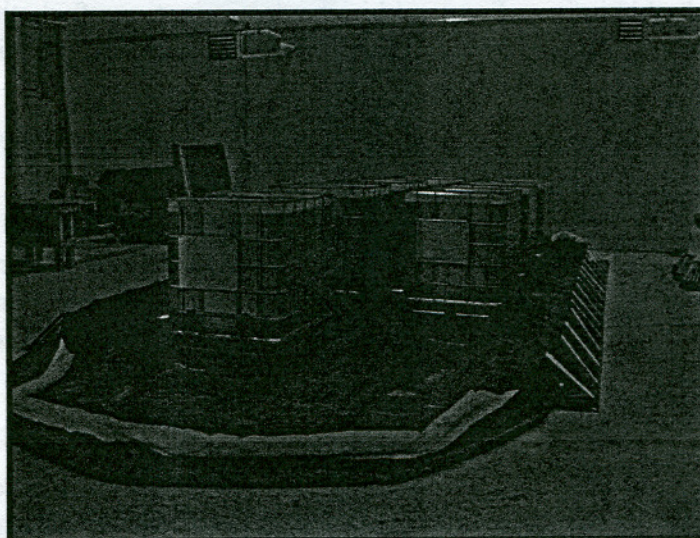


Figure 1. METSS ADF-2 Totes and Secondary Containment

4.0 DEMONSTRATION

4.1 Planned Demonstration Schedule

The demonstration at NFARS was scheduled for 2 - 6 February 2004 to be conducted in accordance with the Demonstrate Alternative Aircraft Deicers Demonstration Plan at Niagara Falls Air Reserve Station, dated 9 January 2004. During this demonstration test, METSS ADF-2 was to be used in its first field demonstration and flight test (however, prior to the demonstration, West Virginia National Guard and the Iowa National Guard had begun using METSS ADF-2 for deicing). The planned demonstration included comparative tests of the METSS ADF-2 and a PG-based deicing fluid on a "grounded" aircraft followed by two actual flight demonstrations using aircraft completely deiced with METSS ADF-2. The demonstration was to be conducted using a KC-135R from the 107th ARW. The planned demonstration activities for the week of 1 February 2004 are summarized in Table 1.

Table 1. Planned Demonstration Schedule Summary

Day	Activity
Day 1: 2 February 2004	Arrive at NFARS. Conduct Demonstration Kick Off Meeting. Finalize planning and coordination for the week.
Day 2: 3 February 2004	Conduct the PG-based ADF and METSS ADF-2 comparative tests.
Day 3: 4 February 2004	Conduct flight tests following a Field deicing demonstration with METTS ADF-2.
Day 4: 5 February 2004	Conduct a repetitive flight test.
Day 5: 6 February 2004	Conduct a Close Out Meeting to summarize demonstration results.

Weather history was reviewed for past five years for the selected demonstration dates to confirm that the weather conditions had the potential to satisfy the needs of the demonstration. However, due to weather conditions and METSS ADF-2 performance, the schedule in Table 1 was modified, as described in Sections 4.3-4.5.

4.2 Activities Prior to Demonstration

Following the Demonstration Plan approved by AFRL, a representative of the CTC demonstration team contacted NFARS to verify that weather and operational conditions were suitable for the planned demonstration. The deicing team was notified that a dedicated aircraft would not be available for the demonstration due to flight operations that would be in progress at that time. NFARS personnel stated that operational aircraft could be used for the demonstration, but the schedule would need to revolve around that schedule. Because the KC-135 SPO had approved METSS ADF-2, no additional coordination with that office was required.

4.3 Demonstration Activities/Observations for Day 1

The demonstration kick-off meeting was held on 2 February 2004 at NFARS. Following introductions, a review of the demonstration schedule was discussed. At this time, the 107th ARW informed the demonstration team that a dedicated aircraft was available for the "grounded" comparison test to be held the following day. However, a dedicated plane would not be available for the flight tests on Days 3 and 4. Operational aircraft would have to be used for the flight demonstrations on both days. 107th personnel would provide the demonstration team with the potential flight schedules to conduct demonstration activities on Days 3 and 4.

The weather forecast predicted freezing temperatures and precipitation for the following day. It was decided to proceed as scheduled for the comparison evaluation of the deicers.

Prior to the team's arrival, the dedicated Landoll deicing truck (85W726) was prepared as the dedicated deicing truck for the METSS ADF-2 deicing fluid. The truck arrived at NFARS filled with water and was drained and flushed three times using a high-pressure

water system. The water was recycled through the tanks and burners. NFARS stated that no soap or additives were used to clean the truck. After the demonstration kick-off meeting on Day 1, the truck was filled with 1,100 gallons (four-275 gallon totes) of METSS ADF-2.

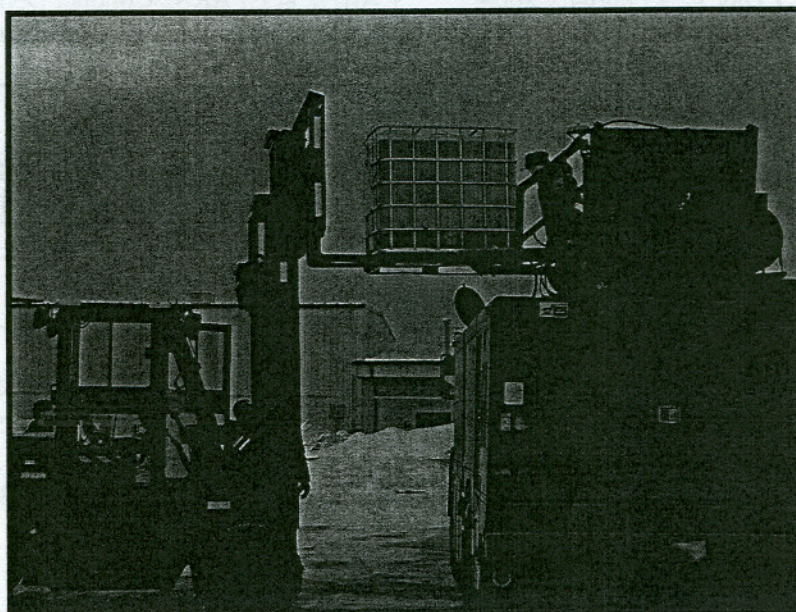


Figure 2. Deicing truck being filled with METSS ADF-2

MD Robotics also arrived on Day 1 and worked with NFARS personnel to set-up their infrared ice detection equipment on a platform truck provided by the 107th ARW. A generator, also provided by the 107th ARW, was used to power the system.

4.4 Demonstration Activities/Observations for Day 2

The demonstration team met at 0715 hours on 3 February 2004, but the weather conditions for Day 2 were not suitable to proceed with the scheduled comparison evaluation. The temperature was above freezing, but was expected to drop through the day. Therefore, the team adjourned until 1300 hours. Conditions at this time still were not suitable to conduct the deicing activities. Temperatures were predicted to drop below freezing the following day. Per the decision table in the demonstration plan, the team decided to postpone activities until the following day. See Appendix B for daily weather conditions.

MD Robotics made several observations using their infrared ice detection equipment. One observation for Day 2 can be reviewed in the MD Robotics summary located in Appendix C.

4.5 Demonstration Activities/Observations for Day 3

The team met at 0715 hours on 4 February 2004 to determine if current weather and operational conditions were suitable to proceed with the demonstration activities scheduled for the day. Both current weather and operational conditions were suitable to proceed; however, the dedicated aircraft for the comparison testing did not have any

frozen precipitation on the surface for deicing. Artificial precipitation would have to be applied by means of a fogging nozzle.

The 107th ARW personnel noted that there was the opportunity to perform one of the deicing flight tests in the morning on an aircraft scheduled for normal operations. Because the METSS ADF-2 was already approved for operational use, the team determined that it was acceptable to perform the flight test in the morning and then proceed with the comparison testing in the afternoon on the static aircraft covered with artificial precipitation.

The team also was informed that the opportunity existed to obtain comparison data for fluid migration by deicing another aircraft scheduled for normal operations (with the current PG-based deicer). The 107th ARW agreed to assist in gathering comparison data by video taping the fluid migration of the METSS ADF-2 and the PG-based deicer on the wing from within each aircraft.

4.5.1 Deicing Fluid Application / Surface Conditions

PG-based deicing fluid (OctafloTM) was applied to the wings of a KC-135R (ANG 91466) in a 50/50 (deicing fluid/water) concentration at 150°F. The fluid application was performed on deicing pad #3 and was completed at 0755 hours. Approximately 50 gallons of the PG-based deicer were applied with the spray wand from a Landoll deicing truck to remove the small amount of snow and frost on the aircraft. A sample of the fluid was collected to verify concentration. The refractive index of the solution was taken after the demonstration was concluded, and it verified that the PG-based fluid was a 50/50 concentration.

METSS ADF-2 in its ready to use (RTU) formulation was applied to a second aircraft scheduled for normal operations. While obtaining fluid temperatures, a discoloration of the fluid was noticed. The fluid appeared to be tinted black; METSS ADF-2 is normally pink in color. According to the METSS representative, the odor and texture of the fluid was typical, but it did appear to be discolored. Therefore, a sample was collected for post-test evaluation. A theory was that some contamination in the deicing truck was causing the discoloration. The team wanted to drain the current fluid and further clean the tank of any contaminants but there was insufficient time to perform this operation and then apply the fluid to the aircraft before it was scheduled to take-off for its normal flight operations. Therefore, it was decided by the team to apply the tinted fluid to the aircraft because it was believed that only the color had changed and the fluid properties were not altered (METSS representatives determined that the specific gravity of the tinted fluid was consistent with virgin fluid).

An interesting point to note is that when this fluid discoloration issue was discussed with a representative from Detachment 3 Warner Robins Air Logistic Center/Product Testing Division (Det 3 WR-ALC/AFTT) after the demonstration was completed, it was discovered that, based on past experience, bio-based products (which includes METSS ASF-2) are typically good cleaners that can strip old deposits. For example, bio-based

fuels have been known to strip 30 years worth of deposits in a fuel system. In this case, the old deposits, which are most likely PG-based deicing fluid and dirt, probably caused the discoloration of the ADF-2 product.

Only a small amount of loose snow and frost resided on the wings of the aircraft prior to deicing with METSS ADF-2 (see Figure 3).

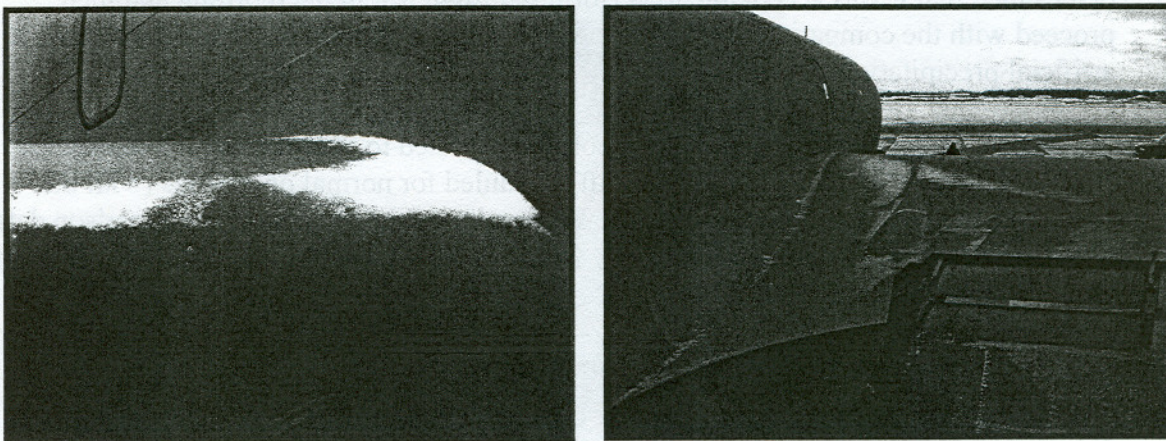


Figure 3. Snow on Aircraft Prior to Deicing with METSS ADF-2

MD Robotics operated the infrared ice detection equipment (see Figure 4) and recorded data for the snow accumulation on the deiced aircraft, as well as for the artificial ice contamination on the grounded plane. Four observations for Day 3 can be reviewed in the MD Robotics summary located in Appendix C.

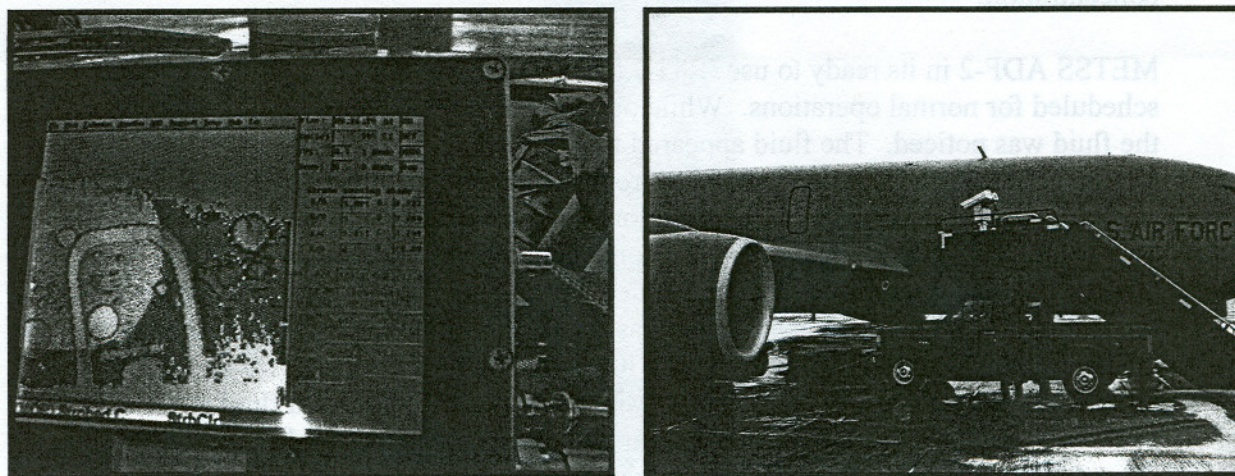


Figure 4. MD Robotics Ice Detection Equipment

METSS ADF-2 was applied to the wings of a KC-135R (ANG 38036), as purchased from Orison Corporation in an RTU formulation, at 147°F. The fluid application was performed on deicing pad #2. Fluid application started at 0830 hours and was completed at 0855 hours. The photographs in Figure 5 capture the application of the METSS ADF-2. Approximately 300 gallons were applied from the cannon and the spray wand of the

dedicated Landoll deicing truck in order to assess the spray patterns and document the migration of the fluid in flight – the excessive amount of ADF-2 sprayed compared to PG was not for deicing purposes. The cannon was used for the general application of the deicer, while the spray wand was used to reach areas that were further away from the bucket. The spray wand also was used to apply the deicer to the nose of the aircraft because the wand allows the operator to have better control of the flow/application to prevent the deicer from reaching the windshield. Because the aircraft sat on the deicing pad for several hours prior to take-off, another 75 gallons of METSS ADF-2 were applied to the wings of the aircraft to re-wet the surface prior to take-off to ensure that the migration patterns of the fluid could be evaluated. The excess METSS ADF-2 was not required for deicing purposes.

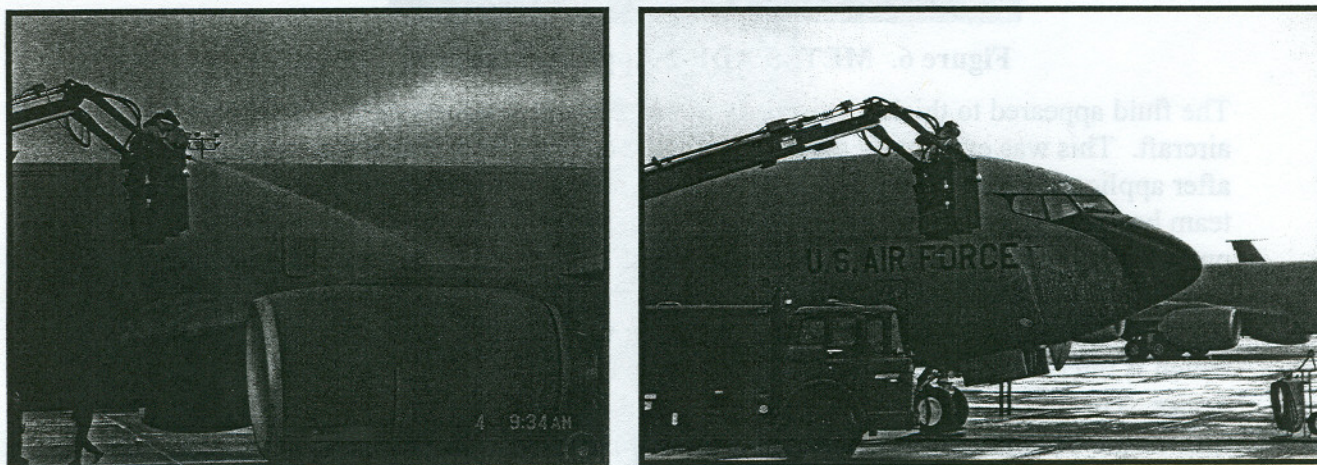


Figure 5. Application of METSS ADF-2

4.5.2 METSS ADF-2 Application Observations

Observations by the team members were consistent. The METSS ADF-2 was compatible with existing equipment because there were no noticeable differences with equipment operation. Based on visual observations, the fluid had a similar viscosity to the currently used PG-based fluid and wetted the surface well. There were no signs of streaking or fisheyes (see Figure 6). Only minor amounts of foaming were present at the drip edges. The demonstration team deemed the foaming to be acceptable because it did not interfere with visual inspection of ice removal. The fluid did have a noticeable odor upon application, but it was not offensive and would not impact deicing operations. Observers did notice a mist in the air during fluid application that felt tacky on participant's coveralls.

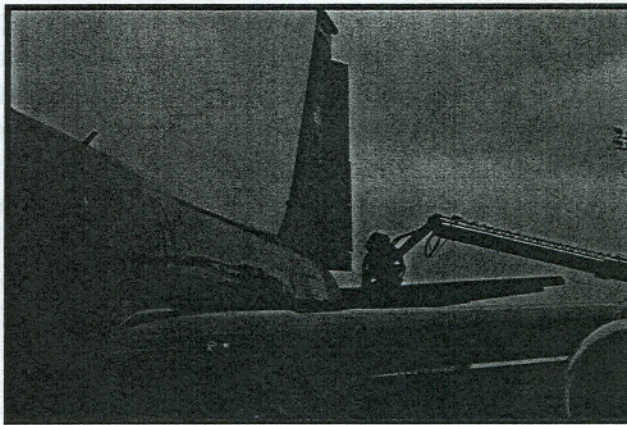


Figure 6. METSS ADF-2 Applied to Aircraft

The fluid appeared to thicken (viscosity increase of the product) on the surface of the aircraft. This was evident by the residue on the deicing truck which was observed shortly after application (see Figure 7). This issue did not cause a concern to the demonstration team because, based on the certification testing, the METSS ADF-2 product was presumed to shear off during take-off and flight. The cause of this significant change in viscosity is unknown at this time. The film on the aircraft (and deicing truck) after deicing was “sticky” and appeared to be similar to the thickness of a thin maple syrup, which is thicker than typically this was observed after the application of a PG-based deicer. This thickness could not be quantified during the demonstration. However, the film on the deicing truck windshield was easily removed with water.

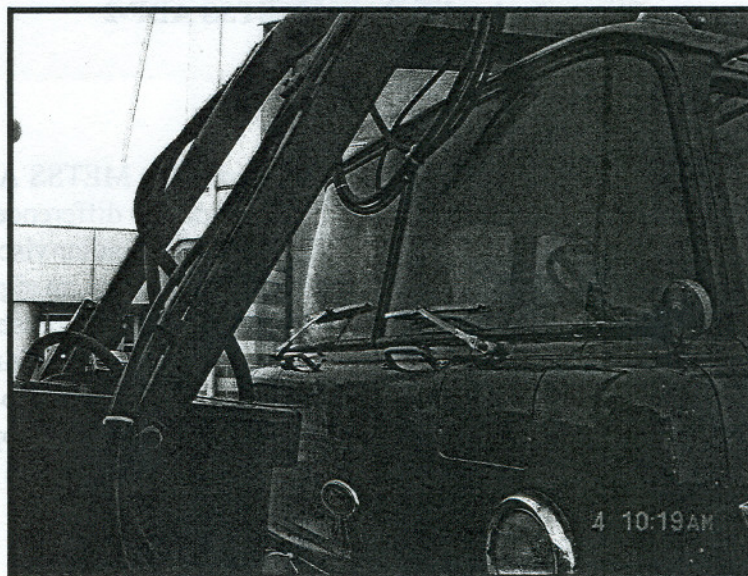


Figure 7. Deicing Truck Residue

4.5.3 Flight Information

The 107th ARW personnel provided the flight details listed in Table 2 to document the flight duration, altitude, and speed of each flight operation for comparison.

Table 2. Flight Details

Deicer Fluid	Take-off Time, hours	Landing Time, hours	Flight Duration, hours	Altitude, feet	Speed, KIAS *
PG-Based	1023	1307 @ McQuire	2.7	28,000	310
	1411	1527 @ NFARS	1.3	29,000	300
METSS ADF-2	1002	1107	1.1	2,000	180

* KIAS = Knots Indicated Air Speed

4.5.4 Post Flight Observations

METSS ADF-2

After the KC-135R aircraft, deiced with METSS ADF-2, landed, the flight crew was debriefed. The crew informed the team that the METSS ADF-2 did not disperse during take-off or flight; however, during flight, deicing fluid had migrated to the windshield of the aircraft and impaired visibility, creating a safety issue. It is important to note that prior to take-off, the ground crew observed a slight speckling of overspray on the windshield, but not to the degree that was found during the post-flight inspection. In addition, the flight crew did not note any handling problems with the aircraft. It was noted that the aircraft may have required more thrust than normal to maintain cruise speed, although the pilot was unsure if it was directly related to the METSS ADF-2. No video could be obtained of the fluid migration due to the fact that the aft observation windows also had a film covering them which was, similar to that on the windshield. The photographs in Figure 8 document the residue on the windows.

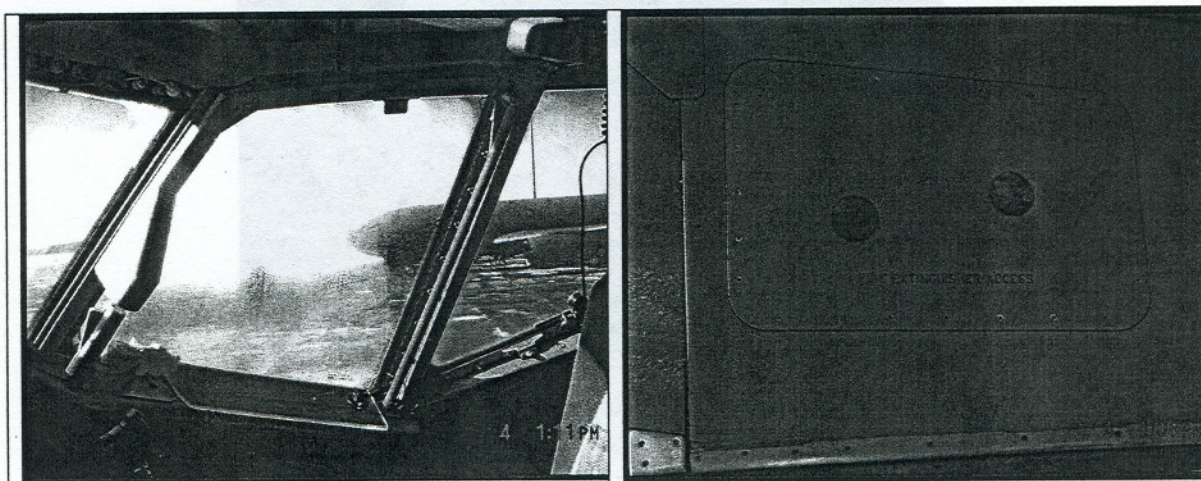


Figure 8. METSS ADF-2 Residual Film on Windshield and Aft Windows

After the flight crew was debriefed, the 107th ARW Maintenance Commander informed the team that the aircraft would need to be washed prior to performing any additional flight operations. He also stated that resources were not available to wash each aircraft after applying METSS ADF-2, which would limit operational capability to meet mission requirements. Therefore, the team was ordered to cease all other demonstration activities due to the operational concerns.

The demonstration team inspected the aircraft. The team observed a non-uniform coat of thick, sticky deicing fluid covering the deiced areas (Figure 9). The fluid did not shear off of the aircraft as expected. There was some migration, but only off the leading edges. It also was noted that on the trailing edge of the engine nacelles, the METSS ADF-2 residue was dark brown and appeared to be “cooked.” Figure 10 shows the effects of heat on the residue.



Figure 9. METSS Residual Film on Engine Cowling

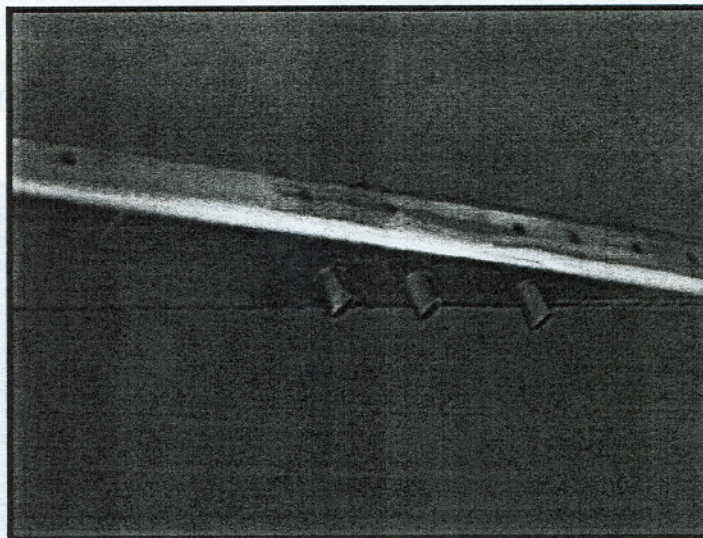


Figure 10. Heat Effect on METSS ADF-2 Residue

Once the inspection of the aircraft was completed, a deicing truck was filled with water and used to rinse the aircraft. The METSS ADF-2 residue was washed off of the aircraft easily with water leaving a clean surface (Figure 11).

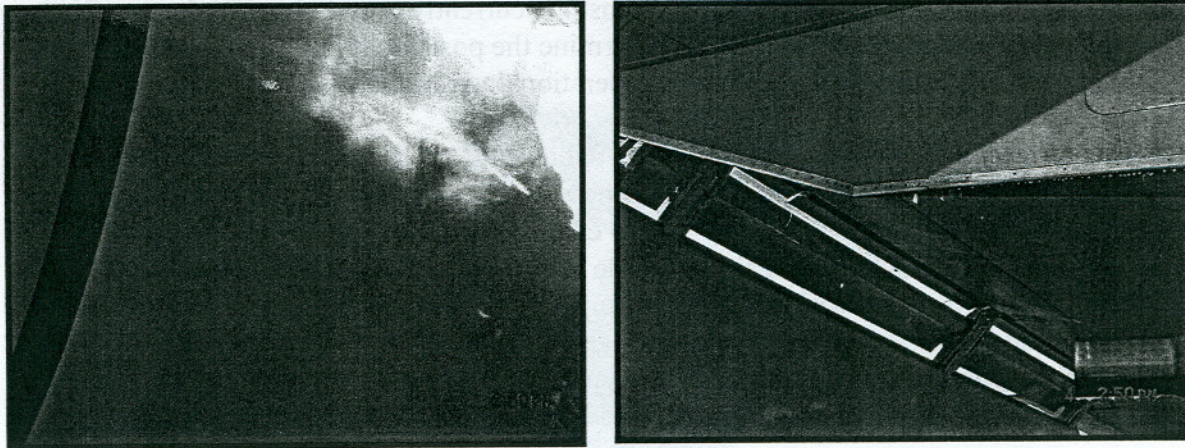


Figure 11. Engine Cowling and Trailing Edge of the Engine Nacelle after Washing

PG-Based Deicing Fluid

Photographs of the KC-135R aircraft deiced with PG-based fluid were taken for comparison purposes. There were only minor amounts of streaking and no significant residue left on the surface, as shown in Figure 12. However, the trailing edge of the engine nacelles did have some dark residue, but not as much as the aircraft deiced with METSS ADF-2. It is worth noting that only 50 gallons of PG-based deicer was applied to this aircraft versus a total of 375 gallons of METSS ADF-2 applied to the second aircraft for evaluation purposes other than solely deicing.

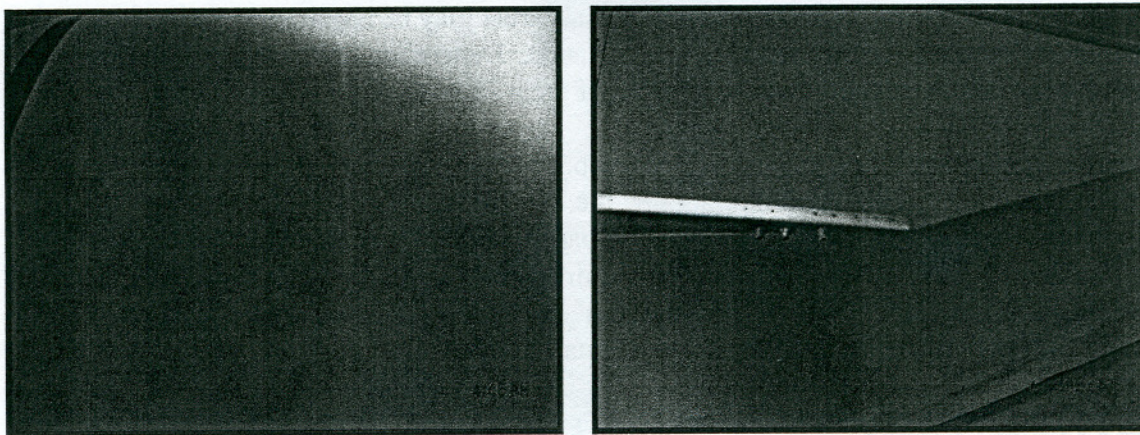


Figure 12. Engine Cowling and Trailing Edge of the Engine Nacelle after Flight of the Aircraft Deiced with PG-based Deicer

5.0 CONCLUSIONS

The specific objectives of this demonstration were to: 1) illustrate the effectiveness of METSS ADF-2 as an operationally suitable deicing fluid; 2) compare the deicing properties of METSS ADF-2 directly against the currently used PG-based deicing fluids in an operational environment; and 3) determine the post-flight migration characteristics of METSS ADF-2 following successful operational use of the fluid.

From the limited demonstration activities conducted, CTC was unable to draw any final conclusions on the actual deicing effectiveness of METSS ADF-2; however, it was noted that the heated METSS ADF-2 was able to effectively remove the small amount of snow and frost on the demonstration aircraft. The team was able to determine that the METSS ADF-2 was compatible with all deicing equipment utilized in this demonstration. The fluid wetted the surface very well, streaking and/or fish eyes were not observed, and no significant foaming was present upon application. In general, the application properties of METSS ADF-2 were similar to that of the current PG-based deicer.

Shortly after application (within five minutes), the fluid viscosity increased significantly. The thickened fluid was observed prior to flight on the deicing truck windshield. Post-flight inspection of the aircraft showed that the thickened fluid remained on the aircraft, indicating that the fluid did not migrate compared to typical performance of the PG-based fluids. The cause of this significant change in viscosity is unknown at this time.

Using a deicer that thickens on the surface of an aircraft can create at least two major concerns. The first concern is a safety issue when the fluid comes into contact (directly or overspray) with any windows on the aircraft, leaving visibility seriously impaired. The second issue involves added drag and reduced lift caused by the thickened METSS ADF-2 fluid on the flight surfaces. Additional thrust may be required to maintain speed and lift and could alter the aircraft's performance. Depending on the type of aircraft and the severity of the effect, this issue may be of great importance.

It also was noted that METSS ADF-2, a bio-based deicer, was an excellent cleaning solvent, which was evident in the fact that the METSS ADF-2 product appeared to be discolored and contaminated by the old PG-based deicing fluid deposits in the deicing truck tanks. Again, the discoloration/contamination did not appear to affect the properties of the METSS ADF-2, with the specific gravity of the solution from the deicing truck verified by the vendor representative.

6.0 RECOMMENDATIONS

In summary, final conclusions regarding the suitability of METSS ADF-2 could not be obtained through this demonstration. Demonstration activities were limited to applying METSS ADF-2 to one aircraft with a minor amount of snow and frost. However, it is believed that the thickening of the METSS ADF-2 fluid on the surface of the aircraft would be similar when deicing multiple aircraft with more ice and snow contamination. Evidence of this comes from the West Virginia and Iowa National Guards, who were

contacted by AFRL after the demonstration. Both guard bases were using the METSS ADF-2 for deicing this winter season, and their deicing crews provided similar observations from their use.

Based on the thickening of the fluid after application to the aircraft surface, the use of the current formulation of METSS ADF-2 is not recommended for deicing on any aircraft in the United States Air Force. Another recommendation of the team is that the Air Force consider adding performance testing to the Engineering Society for Advanced Mobility (Land, Sea, Air, and Space) (SAE) certification for alternative deicing fluids. To date, the Air Force has stopped further procurement of the fluid and has issued a maintenance advisory to inform all bases of the problems associated with using METSS ADF-2. Also, a "tiger team", consisting of representatives from the Air Force and METSS, as well other DoD participants, has been formed to determine the cause of the thickening fluid and develop alternative formulations to rectify the issue.

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Based on the thickening of the fluid after application to the aircraft surface, the use of the current formulation of METSS ADF-2 is not recommended for deicing on any aircraft in the United States Air Force. Another recommendation of the team is that the Air Force consider adding performance testing to its testing program for Advanced Mobility (Land, Sea, Air, and Space) vehicles. The testing program should include testing of alternative deicing fluids. To date, the Air Force has stopped testing of alternative fluids and has issued a maintenance advisory to inform all bases of the problems associated with using METSS ADF-2. Also, a "tiger team," consisting of representatives from the Air Force and METSS, as well as other DoD participants, has been formed to determine the cause of the thickening fluid and develop alternative formulations to resolve the issue.

Appendix A

METSS ADF-2 Certificate of Analysis (COA)

MLI Associates

CERTIFICATE OF ANALYSIS

MANUFACTURER: MLI ASSOCIATES
LOCATION: WESTERVILLE, OH
PRODUCTION DATE: JANUARY 23, 2004
PRODUCT NAME: METSS ADF-2 LOT # PN00F34023
QUANTITY: 2200 GALLONS

CHARACTERISTICS	SPECIFICATION	TEST RESULTS
APPEARANCE	CLEAR, ORANGE	PASS
SPECIFIC GRAVITY	1.19 – 1.22	1.203
FLUID pH	8.4 – 9.2	8.68
BRIX	58 - 62	60.4

COMMENTS:

ANALYST

CERTIFICATE
OF
ANALYSIS

MLL Associates



MANUFACTURER: MLL ASSOCIATES

LOCATION: WEST

PRODUCTION DATE: JANUARY 28, 2004

PRODUCT NAME: METS AD

QUANTITY: 2500 GALLONS

TESTS AD

CHARACTERISTICS	TEST RESULTS
APPEARANCE	PASS
SPECIFIC GRAVITY	1.203
FLUID pH	8.88
BRIX	80.4

Appendix B
Weather Condition Tables for Demonstration Dates

COMMENTS:

ANALYST



wunderground.com

History for Niagara Falls, New York

on Tuesday, February 3, 2004

February 3, 2004

Daily Summary

	Actual	Average (KBUF)	Record (KBUF)
Temperature			
Mean Temperature	28.5 °F / -1.9 °C	24 °F / -4 °C	
Max Temperature	36.0 °F / 2.2 °C	31 °F / -1 °C	50 °F / 10 °C (1952)
Min Temperature	21.0 °F / -6.1 °C	17 °F / -8 °C	-7 °F / -22 °C (1881)
Degree Days			
Heating Degree Days	36	41	
Month to date heating degree days		123	
Since 1 July heating degree days		3817	
Cooling Degree Days	0	0	
Month to date cooling degree days		0	
Year to date cooling degree days			
Moisture			
Dew Point	29.7 °F / -1.1 °C		
Average Humidity			
Maximum Humidity			
Minimum Humidity			
Precipitation			
Precipitation	0.47 in / 1.2 cm	0.09 in / 0 cm	1.35 in / 3 cm (1880)
Month to date precipitation		0.27	
Year to date precipitation		3.43	

Snow

Snow in / cm 0.7 in / 2 cm 8.7 in / 22 cm (1908)

Month to date snowfall 2.1

Since 1 July snowfall 65.0

Snow Depth 09 in / 22.86 cm

Wind

Wind Speed 13.3 mph / 21.4 km/h

Max Wind Speed 20.7 mph / 33.3 km/h

Max Gust Speed 27.6 mph / 44.4 km/h

Visibility 4.9 miles /
8.6 kilometers

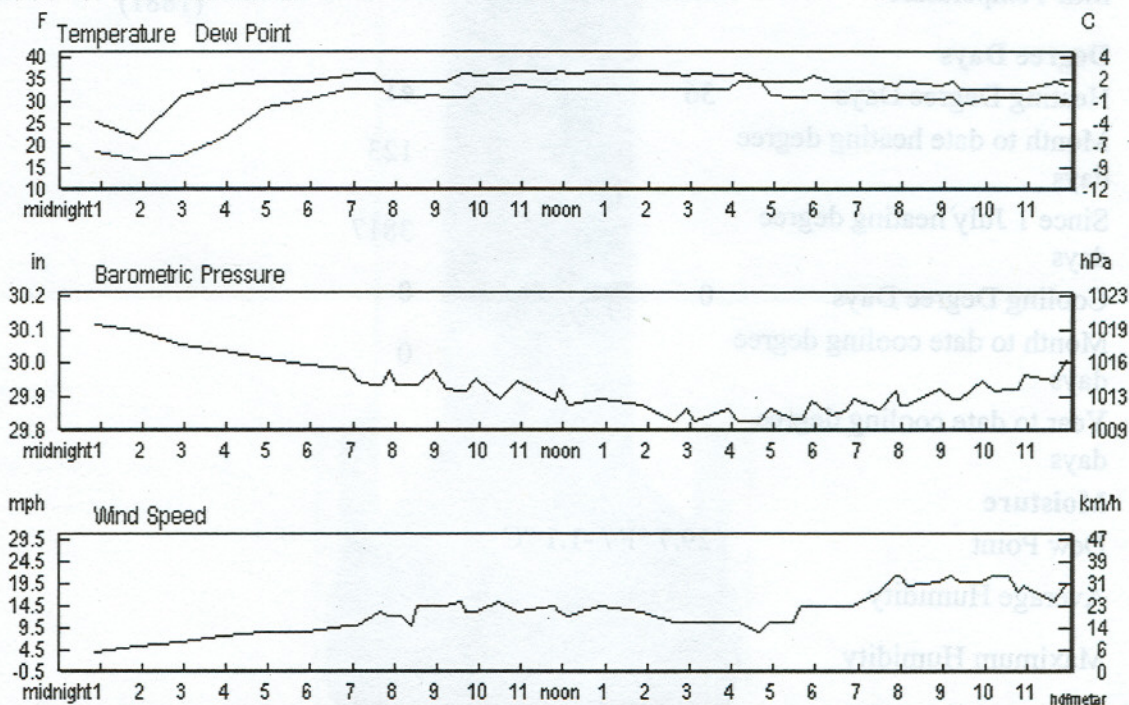
Events

Rain , Snow

Key: T is trace of precipitation, MM is missing value

Source: Averaged Metar Reports

Seasonal Weather Averages



Time(EST)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:53 AM	25.0 °F / - 3.9 °C	18.0 °F /- 7.8 °C	75%	30.11 in / 1019.6 hPa	10.0 miles / 16.1 kilometers	East	3.5 mph / 5.6 km/h	-	N/A		Clear
1:53 AM	21.0 °F / - 6.1 °C	16.0 °F /- 8.9 °C	81%	30.09 in / 1018.8 hPa	10.0 miles / 16.1 kilometers	SE	4.6 mph / 7.4 km/h	-	N/A		Clear

2:53 AM	30.9 °F / - 0.6 °C	17.1 °F /- 8.3 °C	57%	30.05 in / 10.0 miles / 1017.5 hPa 16.1 kilometers	SSE	5.8 mph / 9.3 km/h	-	N/A		Mostly Cloudy
3:53 AM	33.1 °F / 0.6 °C	21.0 °F /- 6.1 °C	61%	30.03 in / 10.0 miles / 1016.9 hPa 16.1 kilometers	South	6.9 mph / 11.1 km/h	-	0.00 in / 0.0 cm	Rain	Light Rain
4:53 AM	34.0 °F / 1.1 °C	28.0 °F /- 2.2 °C	79%	30.01 in / 10.0 miles / 1016.2 hPa 16.1 kilometers	South	8.1 mph / 13.0 km/h	-	0.07 in / 0.2 cm	Rain	Light Rain
5:53 AM	34.0 °F / 1.1 °C	30.0 °F /- 1.1 °C	85%	29.99 in / 6.0 miles / 1015.4 hPa 9.7 kilometers	SSE	8.1 mph / 13.0 km/h	-	0.11 in / 0.3 cm	Rain	Rain
6:53 AM	35.1 °F / 1.7 °C	32.0 °F / 0.0 °C	89%	29.98 in / 6.0 miles / 1015.2 hPa 9.7 kilometers	SSE	9.2 mph / 14.8 km/h	-	0.08 in / 0.2 cm	Rain	Light Rain
7:07 AM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.94 in / 6.0 miles / 1013.8 hPa 9.7 kilometers	SSE	9.2 mph / 14.8 km/h	-	0.02 in / 0.1 cm	Rain	Rain
7:30 AM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.93 in / 5.0 miles / 1013.4 hPa 8.0 kilometers	South	11.5 mph / 18.5 km/h	-	0.05 in / 0.1 cm	Rain , Snow	Light Rain
7:41 AM	33.8 °F / 1.0 °C	32.0 °F / 0.0 °C	93%	29.93 in / 2.0 miles / 1013.4 hPa 3.2 kilometers	South	12.7 mph / 20.4 km/h	-	0.06 in / 0.2 cm	Snow	Light Snow
7:53 AM	34.0 °F / 1.1 °C	30.9 °F /- 0.6 °C	89%	29.97 in / 2.0 miles / 1014.9 hPa 3.2 kilometers	South	11.5 mph / 18.5 km/h	-	0.08 in / 0.2 cm	Snow	Light Snow
8:01 AM	33.8 °F / 1.0 °C	30.2 °F /- 1.0 °C	87%	29.93 in / 2.5 miles / 1013.4 hPa 4.0 kilometers	South	11.5 mph / 18.5 km/h	-	0.01 in / 0.0 cm	Snow	Mist
8:09 AM	33.8 °F / 1.0 °C	30.2 °F /- 1.0 °C	87%	29.93 in / 4.0 miles / 1013.4 hPa 6.4 kilometers	South	11.5 mph / 18.5 km/h	-	0.01 in / 0.0 cm		Mist
8:22 AM	33.8 °F / 1.0 °C	30.2 °F /- 1.0 °C	87%	29.93 in / 4.0 miles / 1013.4 hPa 6.4 kilometers	South	9.2 mph / 14.8 km/h	-	0.02 in / 0.1 cm	Snow	Mist
8:33 AM	33.8 °F / 1.0 °C	30.2 °F /- 1.0 °C	87%	29.93 in / 2.5 miles / 1013.4 hPa 4.0 kilometers	South	13.8 mph / 22.2 km/h	-	0.02 in / 0.1 cm		Mist
8:53 AM	34.0 °F / 1.1 °C	30.9 °F /- 0.6 °C	89%	29.97 in / 2.5 miles / 1014.8 hPa 4.0 kilometers	South	13.8 mph / 22.2 km/h	-	0.03 in / 0.1 cm		Mist
9:10 AM	33.8 °F / 1.0 °C	30.2 °F /- 1.0 °C	87%	29.92 in / 3.0 miles / 1013.1 hPa 4.8 kilometers	South	13.8 mph / 22.2 km/h	-	0.01 in / 0.0 cm	Snow	Mist
9:33 AM	35.6 °F / 2.0 °C	30.2 °F /- 1.0 °C	81%	29.91 in / 5.0 miles / 1012.8 hPa 8.0 kilometers	South	15.0 mph 23.0 mph / 24.1 km/h 37.0 km/h	-	0.01 in / 0.0 cm	Rain	Light Rain
9:41 AM	35.6 °F / 2.0 °C	30.2 °F /-	81%	29.91 in / 5.0 miles / 1012.8 hPa 8.0 kilometers	South	12.7 mph / -	-	0.01 in / 0.0 cm		Mist

		1.0 °C					20.4 km/h			
9:53 AM	35.1 °F / 1.7 °C	32.0 °F / 0.0 °C	89%	29.95 in / 1014.1 hPa	5.0 miles / 8.0 kilometers	South	12.7 mph / 20.4 km/h	0.02 in / 0.1 cm		Mist
10:27 AM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.89 in / 1012.1 hPa	6.0 miles / 9.7 kilometers	South	15.0 mph / 24.1 km/h	0.00 in / 0.0 cm	Rain	Light Rain
10:53 AM	36.0 °F / 2.2 °C	33.1 °F / 0.6 °C	89%	29.94 in / 1013.8 hPa	5.0 miles / 8.0 kilometers	South	12.7 mph / 20.4 km/h	0.01 in / 0.0 cm	Rain	Light Rain
11:46 AM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.88 in / 1011.7 hPa	4.0 miles / 6.4 kilometers	South	13.8 mph 20.7 mph / 22.2 km/h 33.3 km/h	0.02 in / 0.1 cm	Rain	Light Rain
11:53 AM	36.0 °F / 2.2 °C	32.0 °F / 0.0 °C	86%	29.92 in / 1013.1 hPa	5.0 miles / 8.0 kilometers	South	12.7 mph 19.6 mph / 20.4 km/h 31.5 km/h	0.02 in / 0.1 cm	Rain	Light Rain
12:07 PM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.87 in / 1011.4 hPa	4.0 miles / 6.4 kilometers	South	11.5 mph / 18.5 km/h	0.00 in / 0.0 cm	Rain , Snow	Light Rain
12:53 PM	36.0 °F / 2.2 °C	32.0 °F / 0.0 °C	86%	29.89 in / 1012.1 hPa	4.0 miles / 6.4 kilometers	South	13.8 mph / 22.2 km/h	0.03 in / 0.1 cm	Rain , Snow	Light Rain
1:53 PM	36.0 °F / 2.2 °C	32.0 °F / 0.0 °C	86%	29.87 in / 1011.4 hPa	6.0 miles / 9.7 kilometers	South	12.7 mph / 20.4 km/h	0.01 in / 0.0 cm	Rain	Light Rain
2:38 PM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.82 in / 1009.7 hPa	3.0 miles / 4.8 kilometers	South	10.4 mph / 16.7 km/h	0.00 in / 0.0 cm	Rain , Snow	Light Rain
2:53 PM	35.1 °F / 1.7 °C	32.0 °F / 0.0 °C	89%	29.86 in / 1011.1 hPa	4.0 miles / 6.4 kilometers	South	10.4 mph / 16.7 km/h	0.01 in / 0.0 cm	Rain , Snow	Light Rain
3:06 PM	35.6 °F / 2.0 °C	32.0 °F / 0.0 °C	87%	29.82 in / 1009.7 hPa	5.0 miles / 8.0 kilometers	South	10.4 mph / 16.7 km/h	0.00 in / 0.0 cm	Rain	Light Rain
3:53 PM	35.1 °F / 1.7 °C	32.0 °F / 0.0 °C	89%	29.86 in / 1011.2 hPa	5.0 miles / 8.0 kilometers	South	10.4 mph / 16.7 km/h	0.00 in / 0.0 cm		Light Drizzle
4:09 PM	35.6 °F / 2.0 °C	33.8 °F / 1.0 °C	93%	29.82 in / 1009.7 hPa	3.0 miles / 4.8 kilometers	South	10.4 mph / 16.7 km/h	0.00 in / 0.0 cm		Light Drizzle
4:39 PM	33.8 °F / 1.0 °C	33.8 °F / 1.0 °C	100%	29.82 in / 1009.7 hPa	2.5 miles / 4.0 kilometers	SSW	8.1 mph / 13.0 km/h	0.00 in / 0.0 cm		Light Drizzle
4:53 PM	34.0 °F / 1.1 °C	30.9 °F / - 0.6 °C	89%	29.86 in / 1011.2 hPa	4.0 miles / 6.4 kilometers	SSW	10.4 mph / 16.7 km/h	0.00 in / 0.0 cm		Light Drizzle
5:27 PM	33.8 °F / 1.0 °C	30.2 °F / - 1.0 °C	87%	29.83 in / 1010.0 hPa	4.0 miles / 6.4 kilometers	SW	10.4 mph / 16.7 km/h	0.00 in / 0.0 cm		Light Drizzle
5:39 PM	33.8 °F /	30.2 °F 87%		29.83 in /	4.0 miles /	SW	13.8 mph -	0.00 in /		Light

	1.0 °C	/ -	1010.0 hPa 6.4 kilometers	/	22.2 km/h	0.0 cm		Drizzle
		1.0 °C			13.8 mph			
5:53 PM	35.1 °F / 1.7 °C	30.9 °F / - 85% 0.6 °C	29.88 in / 5.0 miles / 1011.6 hPa 8.0 kilometers	SW	22.2 km/h	0.00 in / 0.0 cm		Light Drizzle
		30.2 °F / - 87% 1.0 °C	29.84 in / 8.0 miles / 1010.4 hPa 12.9 kilometers	SW	13.8 mph 22.2 km/h	0.00 in / 0.0 cm		Overcast
6:21 PM	33.8 °F / 1.0 °C	30.2 °F / - 87% 1.0 °C	29.85 in / 6.0 miles / 1010.7 hPa 9.7 kilometers	SW	13.8 mph 22.2 km/h	0.00 in / 0.0 cm		Mist
6:42 PM	33.8 °F / 1.0 °C	30.2 °F / - 87% 1.0 °C	29.89 in / 6.0 miles / 1012.2 hPa 9.7 kilometers	SW	13.8 mph 22.2 km/h	0.00 in / 0.0 cm		Mist
6:53 PM	34.0 °F / 1.1 °C	30.9 °F / - 89% 0.6 °C	29.86 in / 10.0 miles / 1011.1 hPa 16.1 kilometers	SW	17.3 mph 27.8 km/h	N/A		Overcast
7:28 PM	33.8 °F / 1.0 °C	30.9 °F / - 92% 0.6 °C	29.91 in / 10.0 miles / 1012.7 hPa 16.1 kilometers	SW	20.7 mph 33.3 km/h	N/A		Overcast
7:53 PM	33.1 °F / 0.6 °C	30.2 °F / - 87% 1.0 °C	29.87 in / 7.0 miles / 1011.4 hPa 11.3 kilometers	SW	20.7 mph 33.3 km/h	0.00 in / 0.0 cm	Snow	Light Snow
7:58 PM	33.8 °F / 1.0 °C	30.2 °F / - 87% 1.0 °C	29.87 in / 2.0 miles / 1011.4 hPa 3.2 kilometers	SW	18.4 mph 29.6 km/h	0.00 in / 0.0 cm	Snow	Light Snow
8:10 PM	33.8 °F / 1.0 °C	30.2 °F / - 87% 1.0 °C	29.92 in / 2.5 miles / 1013.1 hPa 4.0 kilometers	SW	19.6 mph 31.5 km/h	0.00 in / 0.0 cm	Snow	Light Snow
8:53 PM	33.1 °F / 0.6 °C	30.0 °F / - 89% 1.1 °C	29.89 in / 5.0 miles / 1012.1 hPa 8.0 kilometers	SW	20.7 mph 33.3 km/h	0.00 in / 0.0 cm	Snow	Light Snow
9:11 PM	33.8 °F / 1.0 °C	30.2 °F / - 87% 1.0 °C	29.89 in / 2.0 miles / 1012.1 hPa 3.2 kilometers	SW	19.6 mph 27.6 mph 31.5 km/h 44.4 km/h	0.00 in / 0.0 cm	Snow	Light Snow
9:24 PM	32.0 °F / 0.0 °C	28.4 °F / - 87% 2.0 °C	29.94 in / 2.0 miles / 1013.9 hPa 3.2 kilometers	SW	19.6 mph 31.5 km/h	N/A	Snow	Light Snow
9:53 PM	32.0 °F / 0.0 °C	30.0 °F / - 92% 1.1 °C	29.91 in / 5.0 miles / 1012.8 hPa 8.0 kilometers	WSW	20.7 mph 33.3 km/h	0.00 in / 0.0 cm	Snow	Light Snow
10:12 PM	32.0 °F / 0.0 °C	30.2 °F / - 93% 1.0 °C	29.92 in / 7.0 miles / 1013.1 hPa 11.3 kilometers	SW	20.7 mph 26.5 mph 33.3 km/h 42.6 km/h	0.00 in / 0.0 cm		Overcast
10:30 PM	32.0 °F / 0.0 °C	30.2 °F / - 93% 1.0 °C	29.92 in / 7.0 miles / 1013.1 hPa 11.3 kilometers	SW	17.3 mph 27.8 km/h	N/A	Snow	Light Snow
10:45 PM	32.0 °F / 0.0 °C	30.2 °F / - 93% 1.0 °C	29.96 in / 7.0 miles / 1014.6 hPa 11.3 kilometers	WSW	18.4 mph 29.6 km/h	0.00 in / 0.0 cm	Snow	Light Snow
10:53 PM	32.0 °F / 0.0 °C	30.0 °F / - 92% 1.1 °C						

11:37 PM	33.8 °F / 1.0 °C	30.2 °F /- 1.0 °C	87%	29.94 in / 4.0 miles / 1013.8 hPa 6.4 kilometers	SW	15.0 mph / - 24.1 km/h	0.00 in / 0.0 cm	Mist
11:53 PM	33.1 °F / 0.6 °C	30.0 °F /- 1.1 °C	89%	30.00 in / 5.0 miles / 1015.7 hPa 8.0 kilometers	WSW	18.4 mph / - 29.6 km/h	0.00 in / 0.0 cm	Mist

Astronomy

Sunrise:	07:29 AM (EST)	Moon Rise:	02:36 PM (EST) ^{2/3}
Sunset:	05:29 PM (EST)	Moon Set:	06:04 AM (EST) ^{2/3}

Moon Phase



[more...](#)

Feb. 03 Feb. 06 Feb. 13 Feb. 20 Feb. 27



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History for Niagara Falls, New York
on Wednesday, February 4, 2004

February 4, 2004

Daily Summary

	Actual	Average (KBUF)	Record (KBUF)
Temperature			
Mean Temperature	24.9 °F / -4.0 °C	24 °F / -4 °C	
Max Temperature	33.8 °F / 1.0 °C	31 °F / -1 °C	57 °F / 14 °C (1991)
Min Temperature	16.0 °F / -8.9 °C	17 °F / -8 °C	-9 °F / -23 °C (1918)
Degree Days			
Heating Degree Days	40	41	
Month to date heating degree days		164	
Since 1 July heating degree days		3858	
Cooling Degree Days	0	0	
Month to date cooling degree days		0	
Year to date cooling degree days			
Moisture			
Dew Point	17.9 °F / -7.9 °C		
Average Humidity			
Maximum Humidity			
Minimum Humidity			
Precipitation			
Precipitation	0.00 in / 0.0 cm	0.09 in / 0 cm	0.78 in / 2 cm (1901)
Month to date precipitation		0.36	
Year to date precipitation		3.52	

Snow

Snow in / cm 0.7 in / 2 cm 6.2 in / 16 cm (1917)

Month to date snowfall 2.8

Since 1 July snowfall 65.7

Snow Depth 05 in / 12.70 cm

Wind

Wind Speed 18.0 mph / 28.9 km/h

Max Wind Speed 24.2 mph / 38.9 km/h

Max Gust Speed 35.7 mph / 57.4 km/h

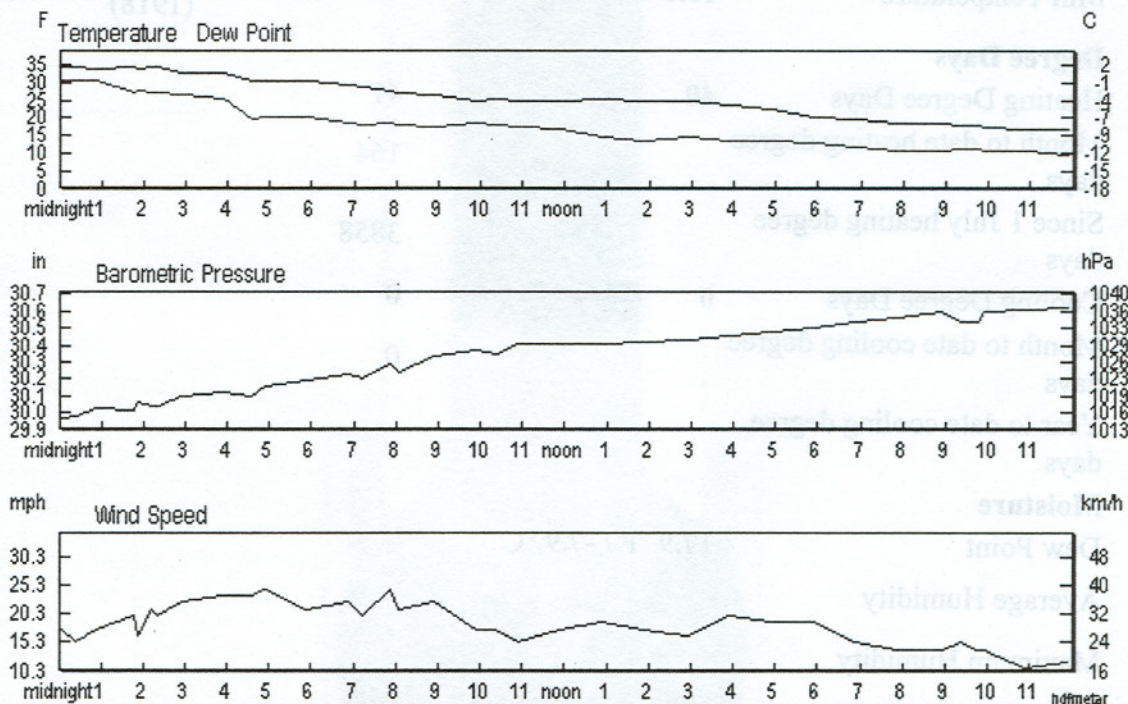
Visibility 9.2 miles /
15.0 kilometers

Events Snow

Key: T is trace of precipitation, MM is missing value

Source: Averaged Metar Reports

Seasonal Weather Averages



Time(EST)	Temperature	Dew Point	Humidity	Pressure	Visibility	Wind Direction	Wind Speed	Gust Speed	Precipitation	Events	Conditions
12:03 AM	33.8 °F / 1.0 °C	30.2 °F / -1.0 °C	87%	29.95 in / 1014.1 hPa	5.0 miles / 8.0 kilometers	WSW	17.3 mph / 27.8 km/h	-	N/A		Mist
12:25 AM	33.8 °F / 1.0 °C	30.2 °F / -1.0 °C	87%	29.97 in / 1014.8 hPa	6.0 miles / 9.7 kilometers	WSW	15.0 mph / 24.1 km/h	-	N/A		Mist

12:53 AM	33.1 °F / 0.6 °C	30.0 °F /- 1.1 °C	89%	30.01 in / 5.0 miles / 1016.3 hPa 8.0 kilometers	WSW	17.3 mph 27.8 km/h	N/A	Mist
1:45 AM	33.8 °F / 1.0 °C	26.6 °F /- 3.0 °C	75%	30.00 in / 10.0 miles / 1015.8 hPa 16.1 kilometers	West	19.6 mph 31.5 km/h	N/A	Overcast
1:53 AM	33.1 °F / 0.6 °C	27.0 °F /- 2.8 °C	78%	30.05 in / 10.0 miles / 1017.5 hPa 16.1 kilometers	West	16.1 mph 25.3 mph 25.9 km/h 40.7 km/h	N/A	Overcast
2:13 AM	33.8 °F / 1.0 °C	26.6 °F /- 3.0 °C	75%	30.02 in / 10.0 miles / 1016.5 hPa 16.1 kilometers	West	20.7 mph 33.3 km/h	N/A	Overcast
2:20 AM	33.8 °F / 1.0 °C	26.6 °F /- 3.0 °C	75%	30.03 in / 10.0 miles / 1016.8 hPa 16.1 kilometers	West	19.6 mph 31.5 km/h	N/A	Overcast
2:53 AM	32.0 °F / 0.0 °C	26.1 °F /- 3.3 °C	79%	30.09 in / 10.0 miles / 1018.7 hPa 16.1 kilometers	West	21.9 mph 28.8 mph 35.2 km/h 46.3 km/h	0.00 in / 0.0 cm	Overcast
3:53 AM	32.0 °F / 0.0 °C	25.0 °F /- 3.9 °C	75%	30.11 in / 10.0 miles / 1019.5 hPa 16.1 kilometers	West	23.0 mph 27.6 mph 37.0 km/h 44.4 km/h	0.00 in / 0.0 cm	Overcast
4:34 AM	30.2 °F / - 1.0 °C	19.4 °F /- 7.0 °C	64%	30.09 in / 10.0 miles / 1018.8 hPa 16.1 kilometers	West	23.0 mph 35.7 mph 37.0 km/h 57.4 km/h	N/A	Overcast
4:53 AM	30.0 °F / - 1.1 °C	19.9 °F /- 6.7 °C	66%	30.15 in / 10.0 miles / 1020.8 hPa 16.1 kilometers	West	24.2 mph 34.5 mph 38.9 km/h 55.6 km/h	0.00 in / 0.0 cm	Overcast
5:53 AM	30.0 °F / - 1.1 °C	19.9 °F /- 6.7 °C	66%	30.18 in / 10.0 miles / 1021.9 hPa 16.1 kilometers	West	20.7 mph 33.3 km/h	N/A	Overcast
6:53 AM	28.9 °F / - 1.7 °C	18.0 °F /- 7.8 °C	64%	30.22 in / 10.0 miles / 1023.4 hPa 16.1 kilometers	West	21.9 mph 29.9 mph 35.2 km/h 48.2 km/h	N/A	Overcast
7:13 AM	28.4 °F / - 2.0 °C	17.6 °F /- 8.0 °C	64%	30.19 in / 10.0 miles / 1022.2 hPa 16.1 kilometers	West	19.6 mph 31.5 km/h	N/A	Overcast
7:53 AM	27.0 °F / - 2.8 °C	18.0 °F /- 7.8 °C	69%	30.27 in / 10.0 miles / 1025.1 hPa 16.1 kilometers	West	24.2 mph 28.8 mph 38.9 km/h 46.3 km/h	N/A	Overcast
8:03 AM	26.6 °F / - 3.0 °C	17.6 °F /- 8.0 °C	69%	30.23 in / 10.0 miles / 1023.6 hPa 16.1 kilometers	West	20.7 mph 29.9 mph 33.3 km/h 48.2 km/h	N/A	Mostly Cloudy
8:53 AM	26.1 °F / - 3.3 °C	17.1 °F /- 8.3 °C	69%	30.32 in / 10.0 miles / 1026.7 hPa 16.1 kilometers	West	21.9 mph 27.6 mph 35.2 km/h 44.4 km/h	N/A	Mostly Cloudy
9:53 AM	24.1 °F / - 4.4 °C	18.0 °F /- 7.8 °C	77%	30.36 in / 9.0 miles / 1028.1 hPa 14.5 kilometers	WNW	17.3 mph 27.8 km/h	N/A	Mostly Cloudy
10:22 AM	24.8 °F / - 4.0 °C	17.6 °F /-	74%	30.33 in / 9.0 miles / 1027.0 hPa 14.5 kilometers	WNW	17.3 mph /	0.00 in / 0.0 cm	Snow Light Snow

		8.0 °C				27.8 km/h			
10:53 AM	24.1 °F / - 4.4 °C	17.1 °F /- 8.3 °C	75%	30.40 in / 9.0 miles / 1029.4 hPa 14.5 kilometers	WNW	15.0 mph / 24.1 km/h	0.00 in / 0.0 cm	Snow	Light Snow
11:53 AM	24.1 °F / - 4.4 °C	16.0 °F /- 8.9 °C	71%	30.40 in / 9.0 miles / 1029.4 hPa 14.5 kilometers	West	17.3 mph / 27.8 km/h	0.00 in / 0.0 cm		Scattered Clouds
12:53 PM	25.0 °F / - 3.9 °C	14.0 °F /- 10.0 °C	63%	30.40 in / 10.0 miles / 1029.4 hPa 16.1 kilometers	West	18.4 mph / 29.6 km/h	N/A		Scattered Clouds
1:53 PM	24.1 °F / - 4.4 °C	12.9 °F /- 10.6 °C	62%	30.41 in / 10.0 miles / 1029.7 hPa 16.1 kilometers	WSW	17.3 mph / 27.8 km/h	N/A		Scattered Clouds
2:53 PM	24.1 °F / - 4.4 °C	14.0 °F /- 10.0 °C	65%	30.42 in / 10.0 miles / 1030.1 hPa 16.1 kilometers	West	16.1 mph / 25.9 km/h	N/A		Scattered Clouds
3:53 PM	23.0 °F / - 5.0 °C	12.9 °F /- 10.6 °C	65%	30.44 in / 10.0 miles / 1030.8 hPa 16.1 kilometers	WSW	19.6 mph / 31.5 km/h	N/A		Mostly Cloudy
4:53 PM	21.9 °F / - 5.6 °C	12.9 °F /- 10.6 °C	68%	30.46 in / 10.0 miles / 1031.5 hPa 16.1 kilometers	WSW	18.4 mph / 29.6 km/h	N/A		Mostly Cloudy
5:53 PM	19.9 °F / - 6.7 °C	12.0 °F /- 11.1 °C	71%	30.49 in / 10.0 miles / 1032.4 hPa 16.1 kilometers	WSW	18.4 mph 24.2 mph / / 29.6 km/h 38.9 km/h	N/A		Scattered Clouds
6:53 PM	19.0 °F / - 7.2 °C	10.9 °F /- 11.7 °C	71%	30.53 in / 10.0 miles / 1033.7 hPa 16.1 kilometers	West	15.0 mph / 24.1 km/h	N/A		Partly Cloudy
7:53 PM	18.0 °F / - 7.8 °C	10.0 °F /- 12.2 °C	71%	30.55 in / 10.0 miles / 1034.3 hPa 16.1 kilometers	WSW	13.8 mph / 22.2 km/h	N/A		Partly Cloudy
8:53 PM	18.0 °F / - 7.8 °C	10.0 °F /- 12.2 °C	71%	30.58 in / 10.0 miles / 1035.5 hPa 16.1 kilometers	WSW	13.8 mph / 22.2 km/h	N/A		Partly Cloudy
9:22 PM	17.6 °F / - 8.0 °C	10.4 °F /- 12.0 °C	73%	30.52 in / 10.0 miles / 1033.4 hPa 16.1 kilometers	WSW	15.0 mph / 24.1 km/h	N/A		Mostly Cloudy
9:44 PM	17.6 °F / - 8.0 °C	10.4 °F /- 12.0 °C	73%	30.52 in / 10.0 miles / 1033.4 hPa 16.1 kilometers	WSW	13.8 mph / 22.2 km/h	N/A		Scattered Clouds
9:53 PM	17.1 °F / - 8.3 °C	10.0 °F /- 12.2 °C	74%	30.59 in / 10.0 miles / 1035.7 hPa 16.1 kilometers	WSW	13.8 mph / 22.2 km/h	N/A		Scattered Clouds
10:53 PM	16.0 °F / - 8.9 °C	10.0 °F /- 12.2 °C	77%	30.60 in / 10.0 miles / 1036.0 hPa 16.1 kilometers	WSW	10.4 mph / 16.7 km/h	N/A		Partly Cloudy
11:53 PM	16.0 °F / - 8.9 °C	9.0 °F / - 12.8 °C	74%	30.61 in / 10.0 miles / 1036.5 hPa 16.1 kilometers	SW	11.5 mph / 18.5 km/h	N/A		Clear

Astronomy

Sunrise:	07:28 AM (EST)	Moon Rise:	03:37 PM (EST) ^{2/4}
Sunset:	05:31 PM (EST)	Moon Set:	06:51 AM (EST) ^{2/4}

Moon Phase



[more...](#)

Feb. 04 Feb. 06 Feb. 13 Feb. 20 Feb. 27



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Sunrise:	07:28 AM	Moon	03:37 PM
(EST)	(EST)	Rise:	(EST)
Sunset:	05:31 PM	Moon Set:	06:51 AM
(EST)	(EST)		(EST)

Moon Phase



Feb. 04 Feb. 05 Feb. 13 Feb. 20 Feb. 27

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Appendix C

MD Robotics Summary

Niagara Fall Air Force Reserve:

1. February 3, 2004, 08:33:29

Contamination: ice at top of the fuselage, above the door.

Weather: overcast, medium to heavy snow falling

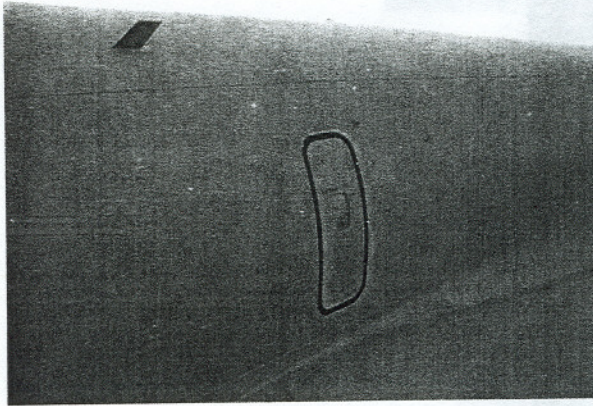


Figure 1 Digital camera view, ice on fuselage, above door

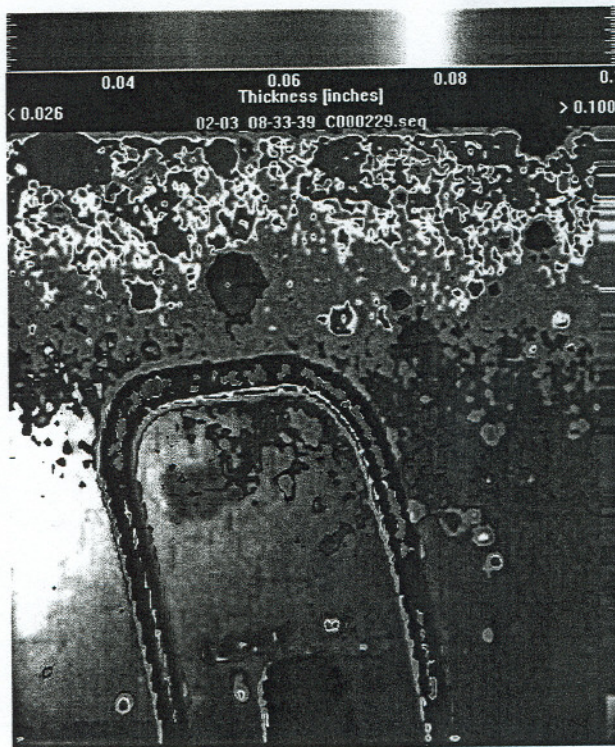


Figure 2 Spectral camera view, ice on fuselage, above door

2. February 04, 2004, 08:07:13

Contamination: clear ice and snow

Weather: overcast, no precipitation

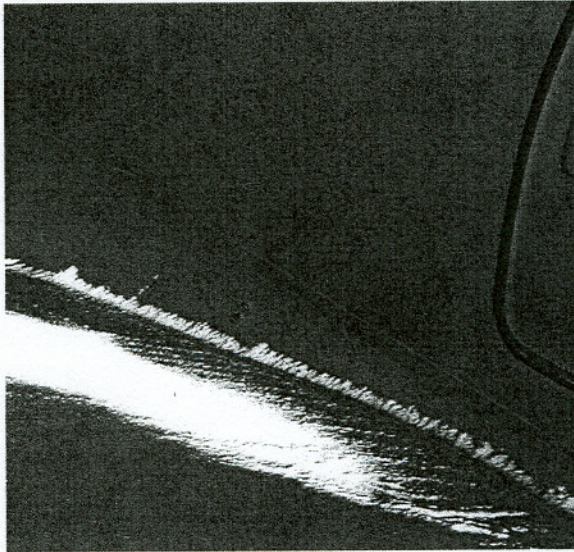


Figure 3 Digital camera view

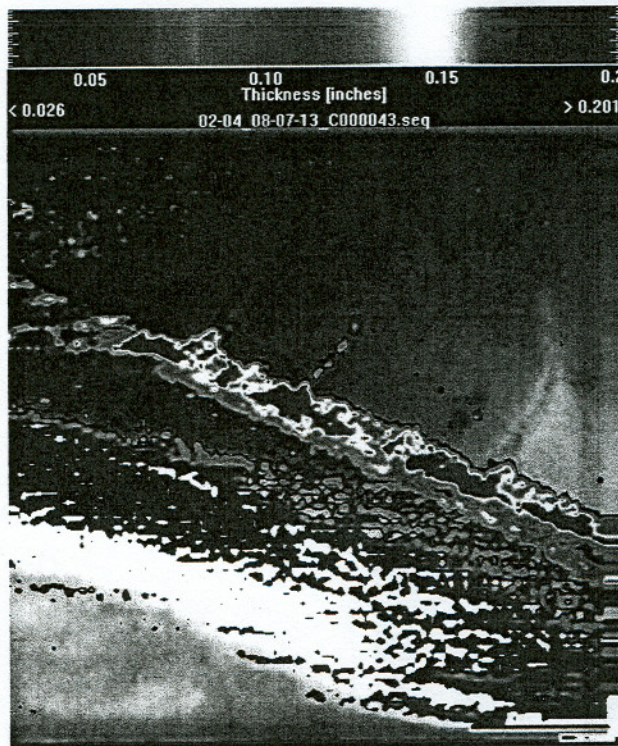


Figure 4 Spectral camera view

3. February 04, 2004, 08:26:53

Contamination: clear ice and snow

Weather: overcast, no precipitation

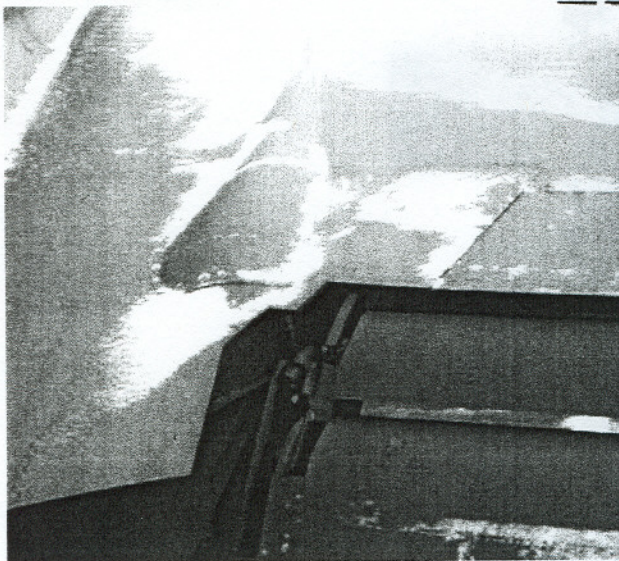


Figure 5 Digital camera view

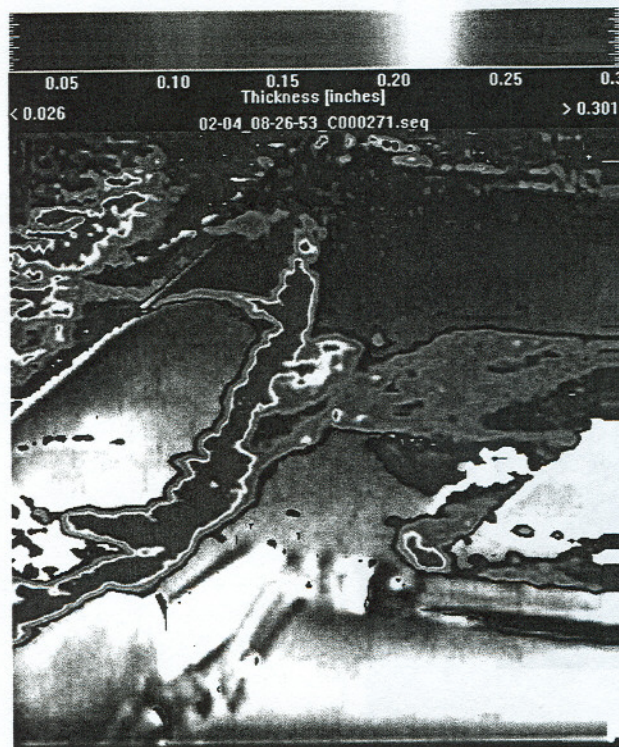


Figure 6 Spectral camera view

4. February 04, 2004, 08:28:57

Contamination: clear ice and snow
Weather: overcast, no precipitation

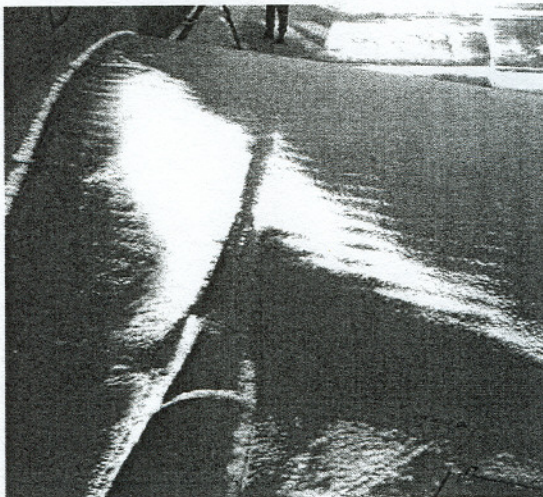


Figure 7 Digital camera view

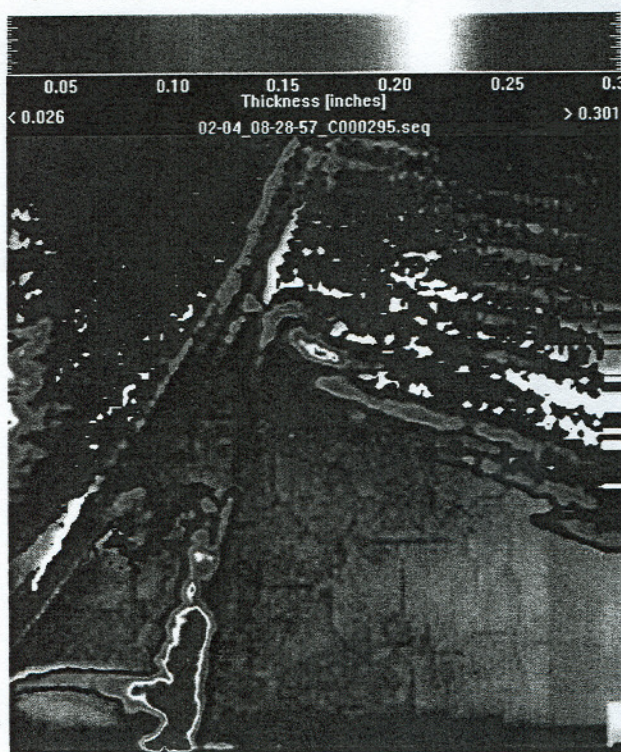


Figure 8 Spectral camera view

5. February 04, 2004, 13:17:31

Contamination: clear ice, starting to melt

Weather: partial clearing, no precipitation, warming up



Figure 9 Digital camera view

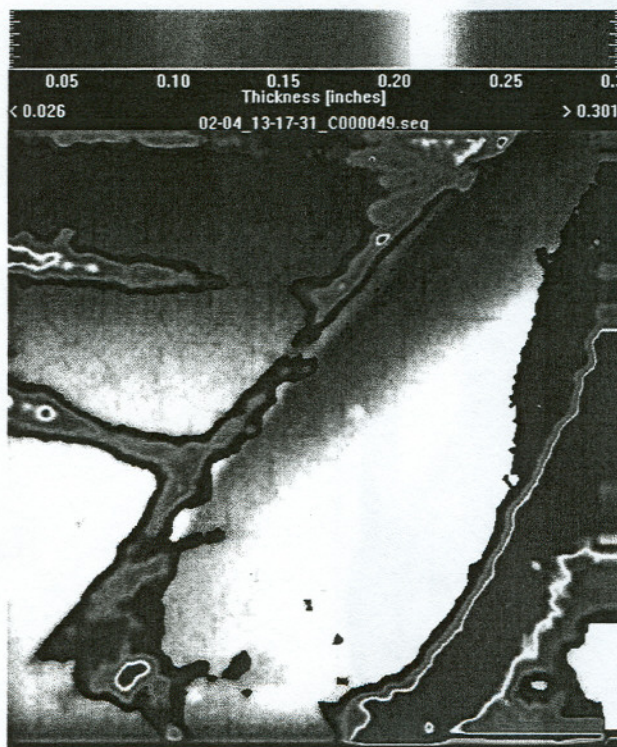


Figure 10 Spectral camera view